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Analysis and Measure of Process Coupling between TQM and Technological Innovation

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Abstract: Based on the process and connotation of total quality management and technological innovation, the coupling between the total quality management process and technological innovation process is analyzed from the relevant theories and existing empirical research. The analysis shows that both theoretical research and existing empirical research can support the coupling between the total quality management process and the technological innovation process. And on this basis, the coupling between total quality management and technological innovation is measured. The measurement results show that: the total quality management and the technological innovation process can be coupled, in a medium-coupling state, and there is a certain room for improvement in the process coupling between the total quality management process and the technological innovation.

1. Introduction

With the continuous improvement of total quality management ideas in enterprise applications, and the trend of companies seeking technological innovation to diversify products and meet consumer needs, the quality and philosophy of new products of the company can gradually meet the needs of consumers, but still There is a lack of product quality level due to the disconnection of the technological innovation process, and the lack of sound innovation systems and innovation management results in low quality management maturity. As quality management research enters the paradigm of quality innovation research [1-2], enterprise managers and scholars begin to explore the use of comprehensive quality management to ensure the introduction of technology and product development, and to improve the quality management of enterprises through the process of technological innovation. The benign coupling between quality management and technological innovation improves the satisfaction of consumers' demands, thereby enhancing the competitiveness of enterprises. However, there are few studies on the coupling effect of total quality management and technological innovation. The specific evaluation of the coupling effect between total quality management and technological innovation, whether the factors that affect the coupling effect can continue to affect the coupling effect between the two, still exists larger research space. Therefore, this paper analyzes the coupling between the total quality management process and the technological innovation process from the relevant theoretical and existing empirical research, and

measures the coupling degree between the total quality management process and the technological innovation process.

2. The Connotation of the Coupling of Total Quality Management and Technological Innovation Process

This section provides the following theoretical basis for the study.

2.1 Total Quality Management Process

Total quality management is the management of all members, the whole process and the enterprise. The basic method of total quality management is the Deming Cycle, which includes planning, doing, checking and action, that is PDCA Cycle. Enterprise quality management activities are to follow the steps of the PDCA Cycle to formulate quality management plans, implement quality policies, check the implementation of quality and correct the remaining problems, and revise the quality management plan according to the processing results, so as to achieve a spiral of quality management. Therefore, the process of total quality management in this paper is divided into four stages according to the PDCA Cycle: quality planning, quality control, quality inspection and quality processing improvement.

2.2 Technological Innovation Process

Generally, technological innovation can lead to product innovation, and the process of technological innovation is the process by which enterprises apply technological means to products and turn products into commodities to achieve economic benefits. From the early stage of technology research and development to product launch, according to the technological innovation process, it can be divided into technological innovation plan, development and production, sales and feedback, technological innovation improvement, and the problems and solutions encountered during the implementation of the technological innovation plan are analyzed and summarized for the next time. Technological innovation provides guarantee, so the process of technological innovation is a continuous improvement process of implementation-improvement-implementation.

Existing research has a large number of technological innovation process studies based on the general activity process of technological innovation from different perspectives. Jin Xin[3] and others divides the technological innovation process into conceptual conception-technological innovation planning stage, research and development activities-technology actual research and development stage and verification and listing-marketing and commercialization stage in the research process. Tan Wenhua[4] divides the technological innovation process into four orderly processes during the research and analysis on the ecologicalization of technological innovation, in which the research and development stage is from creativity to product development, and the two stages of product production and marketing are from Product trial production to commercialization. Li Ying[5] divideds the technological innovation process into three stages: the generation and demonstration of new ideas, product development and production, application and diffusion. Yin Bingnan[6] believes that the technological innovation process includes research and development, determination of research design, production and commercialization of innovation results, and indicates that the activities in each process affect each other. Chen Haoyi and others[7] believe that enterprise information can flow along the process of technological innovation. In the research, the five stages of technological innovation process are research and development, product design, engineering technology, product production, and product marketing. Chen Haoyi and Wang Min and others[8] believe that the technological innovation process is the integration and application of

various innovation elements, and divide the enterprise technological innovation process into five stages. Wang Yumei[9] divides knowledge innovation into five stages according to the technological innovation process, and believes that the knowledge innovation operation mode based on the technological innovation process is a “learning-improve-learning” cycle process. The specific division of scholars on the technological innovation process is shown in table 1.

Table 1: Technological innovation process division.

Process division	Source
Conception, R&D, production, verification and listing	Xin J, Song C, Jinsong X.[3]
Research and development, product production, marketing, technology diffusion	Wenhua T.[4]
Generation and demonstration of new ideas, product development and production, application and diffusion	Ying L.[5]
Research and development, determination of research design, production and commercialization of innovations	Bingnan Y.[6]
Research and development, product design, engineering technology, product production, product marketing	Haoyi C, Ruichuan M, Jianqi M.[7]
Innovative thinking formation stage, product design stage, problem solving stage, product production stage, product sales stage	Haoyi C, Min W, Wenyan W.[8]
Knowledge Innovation Conception, Evaluation, R & D, Commercialization, Reflection Five Nonlinear and Cross-Phase	Yumei W.[9]

In summary, although there are differences in the division of the stages of the technological innovation process, many scholars are based on the general process of technological innovation, mainly focusing on innovation conception, R&D and production, and product commercialization, and including problems in the technological innovation process. Resolution and feedback. Therefore, based on the PDCA process, this article divides the technological innovation process into four stages: technological innovation plan, R&D and production, application and marketing, feedback and improvement.

2.3 The Connotation of the Coupling of Total Quality Management and Technological Innovation Process

(1) Theoretical aspects: The implementation process and purpose of total quality management and technological innovation, related theories, and the development of quality innovation can support the coupling of the total quality management process and technological innovation process.

Total quality management and technological innovation According to the implementation process, there are coupling possibilities in the four stages of PDCA, which can realize technological innovation planning, implementation, and feedback by means of quality management, and improve the total quality management method by the implementation process of technological innovation. The principle of total quality management focuses on the needs of customers and the purpose of technological innovation-to meet the diverse needs of customers, the principle of continuous improvement is the prerequisite for the implementation of technological innovation plans, and the technological innovation process model also pays more attention to process management. Therefore, comprehensive quality management and The implementation process of technological innovation and the purpose support produce a benign coupling.

According to absorptive capacity theory, enterprises have to identify and absorb the factors that are beneficial to achieve a certain goal of the organization, and adopt quality management methods and means in the process of technological innovation, which can effectively guarantee the quality of technological innovation process and promote technological innovation commercialize. Perfecting the total quality management content with the reflection process in the process of technological innovation can improve the quality management level. Therefore, there is a possibility of

transforming the coupling effect formed by the two single systems of the technological innovation process and the total quality management process, and then achieving the organizational goals.

Enterprises are gradually changing from “speed type” to “quality type”. Quality innovation through technology, management, culture, etc. to improve product attributes and meet consumer needs is the key to this transformation. The development and realization of quality innovation is The coupling of total quality management process and technological innovation process provides a theoretical basis. In order to respond to people's multi-level and personalized demand for quality, quality innovation takes into account the improvement of performance standards and the improvement of management systems, and the products or services are converted into benefits through the control of the quality management process. As an important means to improve the inherent attributes of products, technological innovation can effectively meet the diverse needs of consumers and promote the realization of higher benefits. The trustworthy quality signal transmitted by total quality management can create an environment of consumer trust and stimulate consumer demand through market competition. Therefore, in the environment of quality innovation, the organic integration of technological innovation process and total quality management process is more needed.

(2) Empirical research: The empirical research on total quality management and technological innovation mainly focuses on technological innovation as a part of measuring innovation performance. It studies the relationship between total quality management and innovation performance and the research on the coupling of total quality management and technological innovation. aspect.

As part of measuring innovation performance, technological innovation studies the relationship between total quality management and innovation performance. Innovation performance is classified into technological innovation, organizational innovation, product innovation and process innovation[10-12]. Technological innovation is a direct and effective form of enterprise innovation. When conducting research on innovation performance, most scholars study technological innovation as an integral part of innovation performance.

The focus of quality management practices on innovation performance research is different, and there are different effects[13]. Bourke et al.[14] believe in the research that short-term quality innovation management negatively affects product innovation performance, while Zeng J et al. and Escri-tena AB[15,16] conclude that quality management practices have a positive effect on innovation performance. Conclusion. Song Yongtao and others[17], when studying the performance of new product development by quality management practices, the evaluation of new product development performance includes innovative technology adoption and updated indicators. The results of empirical research conducted by Shi Guohong and others[18] show that quality management practices positively affect product and process innovation performance. This shows that quality management practices affect the technological innovation process. In the process of technological innovation, the application of quality standards ensures the implementation of all aspects of technological innovation. Yu Hongwei and others[19] also express in their research that the quality management model can influence the innovation efficiency of enterprises through relevant factors.

In the research on the coupling of technological innovation, some studies have shown that there is a good coupling effect between technological innovation and ecological environment[20], financial innovation[21], economic growth[22], and institutional innovation[23], and it can produce a promotion effect. However, most studies have analyzed the coupling between quality management and technological innovation from a qualitative perspective, and there is still room for improvement in empirical research. Palm K et al.[24] find through research that quality management and innovation can develop in parallel and promote each other. It can be seen from this that quality management and enterprise innovation can be combined, and there is a possibility of generating synergistic

effects and gaining a competitive advantage in the process of mutual promotion. Based on the PDCA process theory, Zhang Zhiqiang[25] constructs a conceptual model and a coupling evaluation model of the process coupling relationship between quality management and technological innovation, and conducted an empirical analysis on the coupling degree of process coupling between quality management and technological innovation. The results show that: enterprise quality management and There is a good process coupling between technological innovations. The relevant empirical research on total quality management and technological innovation can provide a reference for the coupling study of the total quality management process and technological innovation process.

When technological innovation is a part of affecting innovation performance, technological innovation can affect enterprise quality management, and total quality management practices can also ensure technological innovation. The empirical research on the coupling of total quality management and technological innovation process also shows that total quality management and technological innovation can be coupled. In summary, relevant theoretical and empirical research can effectively support the coupling of total quality management and technological innovation. On this basis, this paper measures the coupling degree of the total quality management process and technological innovation process.

3. Construction of the Coupling Measurement Model of TQM Process and Technological Innovation Process

The coupling degree measurement formula is as formula 1. C is the coupling degree between the two systems, where $C \in [0-1]$, The greater the value of C, the greater the degree of coupling between the other subsystems. f_1 and f_2 are the comprehensive contribution of the two subsystems to the coupling degree.

$$C = \frac{\sqrt{f_1 \bullet f_2}}{f_1 + f_2} \tag{1}$$

The comprehensive contribution degree f_1, f_2 of the two subsystems to the coupling degree can be obtained according to the power factor u_{ij} and the weight w_{ij} of each index. The positive and negative power coefficients are obtained according to formula 2 and formula 3, respectively, $\max_{ij}$, $\min_{ij}$ are the upper and lower limits of each specific index of the two subsystems, and w_{ij} is the weight value of each index.

$$u_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{2}$$

$$u_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{3}$$

This paper uses the Cantiere weighting method [26] to measure the weight values in the two subsystems separately. The principle of weight calculation is: according to the correlation coefficient matrix R (formula 4) and standard deviation matrix S (formula 5) of each index, and calculate the eigenvalue and eigenvector of the matrix $R \times S$ (formula 6). Normalize the eigenvector b corresponding to the maximum eigenvalue to get b^*, where $\sum_{i=1}^{m} b_i^2 = 1$. Absolute value of each component in the b^* is the weight of the index w (formula 8).

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{bmatrix} \tag{4}$$

$$S=\begin{bmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \sigma_2 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & \sigma_i \end{bmatrix}, \quad \sigma_i=\sqrt{\frac{\sum_{j=1}^{n}\left(x_{ij}-\bar{x}\right)^2}{n-1}} \tag{5}$$

$$\left(R\times S\right)\times b=\lambda\times b \tag{6}$$

$$b^*=\left(b_1^*,b_2^*,\cdots,b_i^*\cdots,b_m^*\right) \tag{7}$$

$$w_i=\left|b_i^*\right|, \quad b_i^*=\frac{b_i}{\sqrt{\sum_{i=1}^{m}b_i^{\,2}}} \tag{8}$$

4. Measure of the Coupling between TQM Processes and Technological Innovation Processes

The evaluation index system of the coupling measurement of the TQM process and the technological innovation process is based on the index system adopted by Zhang Zhiqiang[25] during the research. The total quality management process (TQMP) and the technological innovation process (TIP) each include 4 aspects (TQMP: TP, TD, TC, TA; TIP: IP, ID, IC, IA), each of which contains 3 specific indicators, and conducts surveys on enterprise managers in the form of online questionnaires. A total of 416 questionnaires were withdrawn, 387 valid data were obtained, and a descriptive statistical analysis was carried out, as shown in table 2.

Table 2: Descriptive statistical analysis.

	Mean	Std. Deviation	Minimum	Maximum		Mean	Std. Deviation	Minimum	Maximum
TP1	4.638	1.103	2	7	IP1	4.553	1.244	1	7
TP2	4.747	1.110	2	7	IP2	4.519	1.268	1	7
TP3	4.793	1.112	1	7	IP3	4.460	1.379	1	7
TD1	4.850	1.162	2	7	ID1	4.525	1.272	1	7
TD2	5.031	1.217	2	7	ID2	4.569	1.365	1	7
TD3	5.153	1.213	1	7	ID3	4.382	1.256	1	7
TC1	5.028	1.212	1	7	IC1	4.401	1.303	1	7
TC2	5.062	1.161	2	7	IC2	4.310	1.304	1	7
TC3	4.930	1.275	1	7	IC3	4.230	1.262	1	7
TA1	4.933	1.268	1	7	IA1	4.370	1.274	2	7
TA2	4.773	1.286	1	7	IA2	4.315	1.342	2	7
TA3	4.804	1.221	2	7	IA3	4.230	1.381	1	7

According to the coupling measure model, the coupling measure of TQM process and technological innovation process is carried out. The correlation coefficient matrix R and the standard deviation matrix S of each index are calculated according to the specific index mean of each measurement dimension as the calculation data.

$$R_1=\begin{bmatrix} 1 & & & & & & \\ 0.468 & 1 & & & & & \\ 0.325 & \cdots & 1 & & & & \\ \vdots & \vdots & \cdots & \ddots & & & \\ 0.112 & 0.178 & \vdots & 0.552 & 1 & & \\ 0.063 & 0.141 & 0.215 & \cdots & 0.563 & 1 & \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix} \quad R_2=\begin{bmatrix} 1 & & & & & & \\ 0.460 & 1 & & & & & \\ 0.386 & 0.599 & 1 & & & & \\ \vdots & \vdots & \vdots & \ddots & & & \\ 0.139 & 0.156 & \cdots & 0.057 & 1 & & \\ \vdots & \vdots & \cdots & \vdots & \vdots & \ddots & \\ 0.095 & 0.062 & \cdots & \cdots & 0.465 & 0.602 & 1 \end{bmatrix}$$

$$S_1=\begin{bmatrix} 0.224 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0.220 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 0.188 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 0.237 & 0 \\ 0 & 0 & 0 & \cdots & 0 & \ddots \end{bmatrix} \quad S_2=\begin{bmatrix} 0.225 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0.221 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \cdots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.241 & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & \ddots & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0.711 \end{bmatrix}$$

The eigenvalues and corresponding eigenvectors of the matrix are solved according to $(R\times S)\times b=\lambda\times b$, and the weight w of each dimension is calculated according to the formula 7, and formula 8. The efficiency coefficient u_{ij} is obtained according to formula 2, formula 3, and the comprehensive contribution degree of the two subsystems to the coupling degree are f_1, f_2 according to the $f_i=\sum_{j=1}^{n}u_{ij}w_{ij}$. The calculation results of weight w, efficacy coefficient u_{ij}, comprehensive contribution degree ,are shown in table 3. Therefore, the coupling degree between the two systems C is calculated according to formula 1, $C=0.500$.

Table 3: Data calculation results.

Dimension	Variables	Indexes	Contribution degree f	weight w	efficacy coefficient u_{ij}
TQMP	TP	TP1		0.215	0.528
		TP2		0.214	0.549
		TP3	0.394	0.259	0.632
	TD	TD1		0.342	0.570
		TD2		0.356	0.606
		TD3	0.665	0.368	0.692
	TC	TC1		0.351	0.671
		TC2		0.354	0.612
		TC3	0.678	0.344	0.655
	TA	TA1		0.293	0.655
		TA2		0.094	0.629
		TA3	0.263	0.021	0.561
TIP	IP	IP1		0.245	0.592
		IP2		0.296	0.587
		IP3	0.506	0.325	0.577
	ID	ID1		0.312	0.587
		ID2		0.258	0.595
		ID3	0.486	0.263	0.564
	IC	IC1		0.288	0.567
		IC2		0.278	0.552
		IC3	0.456	0.260	0.538
	IA	IA1		0.314	0.474
		IA2		0.322	0.463
		IA3	0.453	0.288	0.538

5. Conclusions

The article analyzes the coupling between the total quality management process and the technological innovation process from relevant theoretical and empirical research. The results show that there can be a coupling effect between the total quality management process and the technological innovation process, and the coupling is measured on this basis. The efficiency coefficient of the evaluation dimension in the total quality management process and technological innovation process shows that the quality control (0.665) and quality inspection (0.678) stages in the total quality management process have a higher contribution to the process coupling, quality planning and quality issues processing improvements contribute less to the coupling. In the process of technological innovation, the various dimensions of technological innovation planning, development and production, sales and feedback, and technological innovation contribute to the process coupling more evenly. According to the calculated coupling degree $C = 0.500$, the coupling degree between the total quality management process and the technological innovation process belongs to the medium coupling state. The total quality management process and the technological innovation process are continuously blended and complementary, and gradually develop toward the coupling ideal state.

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